Carbon Nanotube Membranes for Water Desalination and Purification

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Abstract: **The alarming rise in global warming has shown dreadful effect on our ecosystem, among which the most consequential is the salinization of fresh water reservoirs. To meet the demand of freshwater, it has made it urgent to develop an appropriate technology to desalinate and purify water. Traditional desalination methods are implemented in large-scale which need a lot of energy and their capacity to remove salt are limited. Carbon nanotubes are very lightweight hollow tube of 0.8 nanometers wide in diameter, nanotubes are incredibly strong, and they can withstand much higher pressure to desalinate sea water. Researchers have also found that it has tremendous potential for markedly improving the water permeability. Carbon nanotube membrane possesses many advantages, including self-cleaning property and requires less amount of energy to remove the salt ions and provides frictionless transport of water. This review article outlines the basic work done over past decades based on computational and experimental work, providing a detailed description about the current knowledge of utilizing carbon nanotubes in desalination. This article also highlights the current hindrances and future challenges relating to this technology. It is expected to make desalination more affordable, which would be a huge boon to poorer drought stricken countries.**

Keywords: **desalination, fresh water, nanotube, purification**.

I. INTRODUCTION

For the survival of human beings and ecosystems, the availability of freshwater is indispensable. However, stress on the water scarcity problem is due to the fast growth of the economy and urbanization and it requires cost-effective water treatment techniques to produce a high quality of clean water. Human survival depends upon a finite number of freshwater supplies. Over 70% of the world's surface is secured with water, 98% of that is saline water and out of the 2% of freshwater, 90% of it is solidified in ice sheets [1]. On the other hand, global temperature is rising which is causing sea-level rise, glaciers melting and increasing evaporation these are simultaneously making the fresh and seawater saltier and rapidly diminishing the availability of existing freshwater resources. Water scarcity is one the biggest challenge which many countries face as it is fundamental for their economic and social growth.7 billion individuals in 60 nations will experience the harmful effect of water shortage by 2050, according to the United Nations. With 9 billion of the world population is supposed to reach by middle of the century, water shortage with their solution is a challenge to be tackled [2]. A large number of pollutants such as arsenic and biological containments are discharged from the industrial and agriculture sector into water. Sustainable desalination technologies are recently focused to satisfy the growing demand for freshwater for present and future generations [3].

Water scarcity stress has lessened due to the recent advances made in technology and science research by addressing the issues with sustainable water and high quality water supply. Seawater and salty water distillation and treating the processed wastewater from industrial are some techniques that have been used to subdue the water shortage problems. Brackish water and Seawater distillation are among some conventionally used methods, many desalting technologies for distillation are straightforwardly taken into account to generate more freshwater from saline groundwater and sea for the usage of the world. But these conventional technologies need lot of energy and their capacity to remove salt is limited. Saudi Arabia, Israel, and Japan are actively working on to improve desalination technologies and to analyze the feasibleness of a large-scale desalination plant for domestic water supplies [4].

Numerous techniques are being used for the advance water treatment. Amongst them is membrane technology and it is growing the most favored one for desalination and water purification. According to their molecular weight cut-off and their configuration membranes are distributed into different classes. Membrane processes such as ultrafiltration (UF), microfiltration (MF), reverse osmosis (RO), nanofiltration (NF) and membrane distillation (MD) are widely adopted in water purifying processes. Polymeric, ceramic and hybrid material are mostly used to produce membranes. Polymeric membranes have excellent mechanical strength and at the same time ceramic membranes possessed good thermal and chemical stabilities. Anyhow, both of these types of membrane have limitation for example ceramic membranes are usually employed for small-scale because of high cost [5].

The desalination technology science is encountering a shocking revolution where the utilization of nanotechnology is advancing quickly it includes another worldview of research. Carbon-based nanomaterials (CBNs), for example, carbon nanotubes are now and again examined and they have been offered as a guaranteeing open door for improving the capacity and proficiency of a right now accessible desalination framework to fulfill the need of freshwater supplies. New research on unique utilization of CNTs in desalination has offered enormous chances and plausibilities for further advancement in innovation [6].

Carbon nanomaterial shows some unique properties like self- cleaning, mechanical strength, thermal and electrical properties [3]. High flux membrane separation performance is favorably allowed by CNTs because it could expedite the fast frictionless transport of liquid and have a very smooth hallowed structure Carbon nanotube diameter size is so small and precise, it efficiently expels most ions because of energy barriers being at the entries of the channel from merely water molecules are permitted to pass into the hollow nanotube [6]. To enhance membrane performance CNTS can be used in two ways filler or as direct filters. Carbon nanotubes have shown enormous fillers in different membranes because of disinfection, fouling resistance behavior, stability, and rejection and permeability. [7]

Nanotechnology is expected to drive the high cost of desalination further down; despite these unique properties this newly rising technology is facing numerous challenges and obstacles in its development. This review article highlights the basic work done over the past decades based on experimental and computational work. Furthermore, it provides a detailed description of the current knowledge of the utilization of carbon nanotube membranes and also presents the novel properties of carbon nanotube membranes. This review article outlines the existing obstruction and future hurdles relating to this technology. It is expected that novel nanostructured material is anticipated to perform an indispensable role in forming a future pattern in membrane material research in just a matter of time.

A. Carbon nanotubes membrane

A.1. Basic information about carbon nanotubes

CNTs are made up of a rolled-up sheet of single-layer graphene in which carbon atoms are at the side of a hexagon, ordered in sp2 hybridization [8]. A carbon nanotube can be single-walled (SWCNT) with a width of less than 1 nanometer (fig. 1a) or multi-walled (MWCNT) comprising of numerous concentrically interlinked nanotubes, with diameter approaching more than 100 nm (fig. 1b). Carbon nanotubes can be synthesis by three-technique chemical vapor deposition (CVD), laser ablation of graphite and arc discharge. One of the most widely recognized strategies for CNT production is chemical vapor deposition. In this strategy, the manufacturer joins a metal catalyst with carbon-containing reaction gases like hydrogen to form carbon nanotubes on the catalyst inside a high-temperature furnace [9].

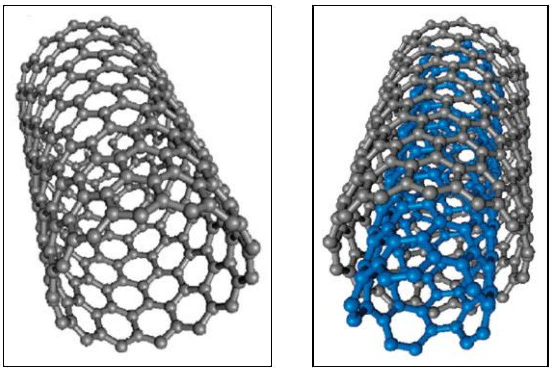
(a)  (b)

Figure1. (a) Morphology of a single-wall carbon nanotube (SWCNT) and (b) Morphology of a multiwall carbon nanotube (MWCNT) [16].

A.2. Comparison between single-wall carbon nanotube and multiwall carbon nanotube

SWCNTs are made up of single graphene layer it is difficult to synthesis in bulk and its purity level is low whereas MWCNTs are made of multiple graphene layers it is easy to synthesis in bulk and it has high purity level. They also differ in properties, for example, the specific gravity of SWCNT is 0.8g/cm3, as well as the electrical and thermal conductivity of SWCNT, which is 102-106 and 6000 respectively whereas the thermal and electrical conductivity of MWCNT, is 2000 and 103-105 respectively and a specific gravity of MWCNT is 1.8g/cm3 [21-22].

A.3. Novel properties of carbon nanotube

CNTs have novel morphological properties along with adsorption abilities and water permeability that are credible for membrane separation. Scientists have effectively examined the ability of CNTs to help as adsorbent media to expel a broad scope of chemical and biological impurities. The outstanding results got in the adsorption ability are chiefly connected with its functional structural and just as microbial cytotoxicity that has halfway impact on a concentration of biological contaminants [10]. It is additionally worth to mention that the utilization in desalination also provides some other important advantages rather than its extraordinary transport properties. High tendency membrane scaling is produced by the precipitation of sparingly soluble salt when a high concentration of salt particles in salty and seawater go through it. Furthermore, with the constant appearance of miro- contaminants those most plausibly cause membrane biofouling. Different strategies such as antiscalant addition, Ph adjustment chemical cleaning and antiscalant addition are adopted to reduce biofouling issues. CNTs possess notable biofouling resistance because of cytotoxic properties that mean it kills microbes that might otherwise foul up their surfaces. [11]

One of the different properties of CNTs is that they are very strong tensile strength is a proportion of the measure of force an item can endure without tearing separated. Steel has roughly multiple times less tensile strength than of CNTs of a similar diameter. Strong tensile strength is a direct result of an interlocking carbon-carbon covalent bond. Nanotubes are strong yet additionally elastic. This implies it takes a great deal of force to bend a nanotube, yet it will spring right back to its unique position when you discharge it. [12]

A.3. Types of carbon nanotube membranes

The two broad classes of carbon nanotube membranes are freestanding and the other is mixed CNT membranes according to the fabrication method and freestanding CNTs are further divided into two main types are vertical aligned carbon nanotube (VA-CNT) membrane and bucky- paper membrane. In the VA-CNT membranes, Carbon nanotubes are aligned as cylindrical pores that force the fluid to pass only across the hollow CNT inside or between the CNTs bundles [9]. An interesting technique to treat water is to use CNT as a hollow tube to remove biological contaminants from water. On the other hand, bucky papers are a simple type of membrane that consists of a self-supporting, entangled assembly of CNTs. Bucky papers are often flexible material; however, they also exhibit Chemical and physical stability due to their natural thermal and mechanical properties [5]. Lately, the synthesis of mixed CNT membranes for water purification has become the center of the focus of many scientists because of their permeability and antifouling property. The thin-film composite RO membrane has a similar structure to the CNT mixed membrane, where the top layer of mixed CNT membrane is mixed with the CNT and a polymer. The resultant membrane is notable for UF, RO and FO membranes in water treatment. The quick transport of water is because of a hydrophobic hollow tube of CNTs. this allows the CNT membrane to displace both reverse osmosis and ultrafiltration with limited or no loss of energy.

B. Carbon nanotube based water treatment technology

B.1. Carbon nano tube for water purification

There are two kinds of contaminants found in water organic and inorganic and the two of them are dangerous to human health. Organic contaminants in water might be found as particulate or dissolved materials resulting from animal or plant rot, along with human activities. There are different sorts of organic compounds discharged by human activities that incorporate pharmaceutical and personal care products (PPCP), herbicides and pesticides. These organics may cause health effects. Consequently, it is essential to create a unique high-filtration capability. Functional carbon nanotube (f-CNT) membranes are custom-made to the expulsion of organic contaminants from water. The studies have shown that f-CNT has a high adsorption affinity to a broad range of organic containments. The removal system of the f-CNT membrane towards organic contaminants is typically happening because of chemical adsorption and hydrogen bonding [13]. Protozoa, infections and microscopic organisms are generally discovered pathogenic micro-organisms in wastewater effluent and drinking water. Past investigations expressed that CNT is equipped for removing inactivating or a broad scope of micro-organisms, which incorporates bacteria. SWCNTs inactivated E.coli because of the invasion of SWCNTs into their cell wall and furthermore chemically altered CNTs are more effective than pristine CNTs and the cell wall of the microorganisms is destroyed by the polymeric membrane [14].

B.2. Carbon nanotubes for desalination

98% of all water on the earth is brackish and ocean water, catching a little part is expected to give an immense effect on the water shortage problems. Subsequently, membrane separation technology has been broadly acknowledged as an assuring course to allow manageable freshwater more economically. Recently, Carbon nanotubes are curiously explored and have captured significant growing attention of researches because of their characteristics to heighten the ability and performance of conventionally used membrane separation techniques such as RO. Due to their high hydrophobicity and simple morphology, CNTs are regarded as a model framework to examine ion and water transport. The water transport through CNT channels represents a novel nanofluidic framework and it has demonstrated the comparability between their fluid transport channels in the biological membrane. Even though the quick water transport presently can't seem to be completely comprehended, it has been proposed that high flux water transport through CNTs is conceivable because of the weak interaction of the water molecule with hydrophobic wall combine with the smooth nature of the wall to facilitate nearly frictionless transport of water. Molecular ordering phenomena inside the nanopores and atomic-scale smoothness of the CNT offer high flux transport (fig. 2) [15].The concentration of ions in the feed water may fundamentally influence the desalination performance of the membrane; the impact of ion concentration might overcome, because of the easy water penetration property of the carbon nanotube membrane. Moreover, especially-aligned carbon nanotubes may make desirable channels in the membrane permitting a profoundly productive desalination performance. The carbon nanotube membranes are more affordable than RO and forward osmosis (FO).

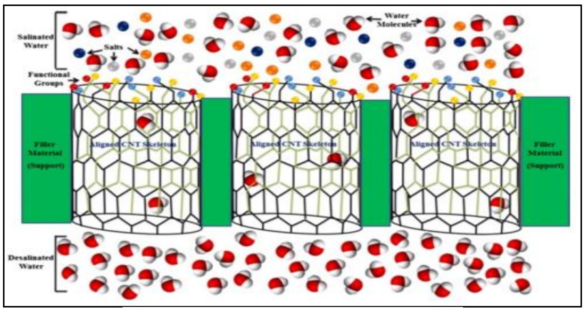


Figure 2: Carbon nanotube (CNT) [17].

C. Comparison between carbon nanotube membranes with currently used membrane

CNT membranes are a more efficient membrane than other conventional used membranes such as UF, NF and RO. CNT membranes are cost-effective than these membranes and it posses unique characteristics like fouling resistance, high permeability and less consumption of energy whereas these conventionally used membranes have low fouling resistance, low permeability and they also consume a high amount of energy. Pore size is also different for each of the membranes such as the pore size of the CNT membrane is between 0.8-100nm, the pore size of the UF membrane is between to 2-50nm, the pore size of NF is less than 2nm and RO membrane has no pores. A comparison between CNT membranes with currently available membrane is given in table 1[13]

TABLE 1: Comparison between currently available membranes with CNT membrane.

	CNT membrane	UF membrane	NF membrane	RO membrane
Definition	It is an open-ended single hollow structure or polymer Composite arranged perpendicularly to the surface of an impermeable filler matrices.	>1-100 nm is a range of solutes size remove through this process.	Less than 2nm size of particles are remove through this process.	This process is used to remove salt ions from water when it pass through partial permeable membrane.
size of pore	0.8-100nm	It is between 2-50nm	Less than 2nm	Non- porous
Characteristics	Energy utilization is less	Utilization of energy is moderate	Utilization of energy is high	Utilization of energy is high
	Excellent performance	Moderate performance	Excellent performance	Excellent performance
	Antifouling	Low fouling resistance	Low fouling resistance	Low fouling resistance
	Cost-effective	Less cost-effective	Less cost-effective	Less cost-effective
	High stability	Low stability	Low stability	Low stability
Water treatment applications	Water purification, desalination of brackish water and industrial waste water treatment.	Ultrafiltration(UF) is used to remove bacteria, suspended solid, viruses and endotoxins with a help of pressure-driven barrier.	Nanofiltration is used for softening and it is used for removal of organic matter.	Water reuse, desalination and water purification.

D. Current obstruction and future hurdles

The utilization of CNTs is of enormous benefit in the field of desalination. Current advancement makes practical to state that carbon nanotubes may be one of the most tenable answers for diminishing energy utilization to facilitate the progressively manageable improvement of desalination technology. In any case, various basic issues stay open. Synthesis and processing are some of the most basic difficulties which may prevent further advancement [18]. Although experimental and computational investigations have given strong proof that CNTs can be utilized to create a high-flux membrane, on a huge scale, CNTs are hard to make with an appropriate pore size and distribution is as yet a fundamental impediment in the utilization of CNTs on a business scale. Another obstacle that limits the uses of CNTs in large- scale operation is the cost of CNTs, particularly SWCNTs. Even though researchers are looking for building up an efficient procedure for the large scale manufacturing of CNTs, the present expense does not propose the uses of CNTs on a huge scale. However, it is expected that due to the increase in the commercial production of CNTs, their cost will be significantly decreased later on [19].

Besides, the possibly hazardous impacts of CNTs on the health of humans and the environment put serious inquiries to be replied. The arrival of CNTs into the environment is another significant issue now. Proof for the dangerous impacts of these built particles has been found in model organisms. Researchers have likewise recommended that CNTs show solid associations with heavy metal ion and organic compounds because of their surface functionalization group and hydrophobic surface. Hence, the impacts of CNTs on basic condition contaminants should be assessed. The novel characteristics of CNTS must be created and used inside a maintainable system to lessen the environmental ramifications to shield the feasible utilization of CNTs in desalination technology [20].

Another deterrent is the problems in carbon nanotube development with the alignment in vertical aligned carbon nanotube layers. Membrane properties, for example, flux and salt rejection are affected by the irregular alignment. Additionally, look into is required to viably deliver this problem to intensify membrane efficiency. Viable strategies to functionalize the tip of carbon nanotube without trading off the CNT characteristics should likewise be researched [20].

The important question is, can this developing nanotechnology diminish the problems related to water desalination? There is as yet far to go to investigate and produce this material, especially with the intriguing new properties that can be found through this captivating material.

II. CONCLUSION

The advancement of nanomaterial for water treatment and desalination is a developing field meaning to satisfy the consistently expanding interest of freshwater around the globe. Among these, CNTs have increased enormous consideration for creating membrane because of their morphological properties just as water permeability and adsorption capacities that are tenable for membrane separation. Carbon nanomaterial demonstrates some novel properties such as self-cleaning, mechanical quality, thermal and electrical properties. CNTs can positively offer high- flux membrane separation performance because CNTs have a smooth hallowed structure and could facilitate the quick frictionless transport of fluid. Even though there are as yet numerous obstacles, the ongoing research patterns suggest that numerous enhancements in synthesis methods and the use of the CNT membrane are expected shortly. This technology expected to make desalination more affordable, which would be boon to poorer drought-stricken countries.

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